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Soiling Degradation by Atmospheric Aerosols in an Urban Industrial Area

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SOILING DEGRADATION BY ATMOSPHERIC AEROSOLS IN AN URBAN INDUSTRIAL AREA

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16. ABSTRACT Particulate matter deposited from atmospheric aerosols during a thirteen week study in Elizabeth N.J. was examined in an attempt to identify the portion of the aerosol primarily responsible for soiling degradation. White painted panels were exposed to the atmosphere in sheltered and in unsheltered locations, and oriented horizontally and vertically in each. The reflectivities of all panels to visible light were measured weekly as a measure of soiling. In addition, TSP, fine aerosol fraction and coarse aerosol fraction were measured each week. The number and size distribution of the particles deposited on the panels were determined by the examination of scanning electron micrographs. The results show that the fine particles deposit in greatest number, but the coarse particles have the largest effect on area coverage. Large particles are present in lesser amount on the unsheltered horizontal panels, but fine particles in essentially the same amount on both horizontal panels. It appears that rain removes the coarse particles.

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SOILING DEGRADATION BY ATMOSPHERIC AEROSOLS IN AN URBAN INDUSTRIAL AREA

The gradual and progressive soiling of structures exposed to the atmosphere is commonplace. Wooden homes required painting every few years for aesthetic purposes as well as for preservation, while public buildings, houses of worship, and statuary require occasional cleaning of their exterior because of gradual soiling. The soilant is usually a component of atmospheric aerosols. This paper presents the results of a study that attempts to identify the components of the atmospheric aerosol primarily responsible for the observed soiling of exposed materials.

The site chosen for the study was in Elizabeth, N.J., an urban area with a mix of residential, commercial, and industrial facilities.[1] The test site was close to various sources of aerosols. Since the site is close to major highways on three sides -- the New Jersey Turnpike, U.S Routes 1 and 9 , and Interstate Route 287 -- automobile and diesel truck traffic abounds, and road dust is prevalent. Oil refineries and chemical plants lies to the south and south-west, and an international airport is located about 3 1/2 miles to the north, north-east. The Arthur Kill and the Newark Bay, both navigable waterways, lie to the east.

METHODOLOGY

Soiling was assessed by exposing white-painted boards to the outdoor atmosphere, and measuring the reflectance of visible light from the surface of the boards once per week over a thirteen week period. Four white-painted boards were exposed. Half of each was painted with flat white paint, the other half with glossy white paint. Two of the boards were exposed in an unsheltered location, the other two were sheltered. In each of the locations one board was oriented horizontally and the other vertically.

Reflectance was measured with a Pacific Scientific Gardner/Neotec Instrument Division Colorgard 45/0 Reflectometer. The Reflectometer was connected to A.C. power when used, in order to eliminate any error from possible variation in the power of the batteries, and the instrument was calibrated against standard reflectances immediately prior to each use.

In addition, glass slides were affixed to each of the boards and analyzed for the deposited particles. The glass slides were painted with the same paint -- flat or glossy -- as the corresponding half of the board, and later examined by scanning

electron microscopy for both particle count and size distribution. The two sheltered boards were also provided with three carbon-coated glass slides for elemental analyses. One of the three carbon-coated slides was removed from each sheltered board after exposure periods of three weeks, six weeks and thirteen weeks. All slides were sent to the Environmental Protection Agency, Atmospheric Sciences Research Laboratory, at Research Triangle Park, which performed the elemental analysis and the microscopy.

The total suspended particulate matter (TSP) was measured with an Andersen high volume filter at a cycled, intermittent sampling period of 5-minutes per hour at a flow rate of 40 cfm through an 8" x 10" Gelman Sciences type A/E glass fiber filter. Filters were changed weekly and weighed. Flow rate was correlated with suction pressure at the filter, and measured before and after every filter change.

To compensate for particles that may deposit upon the filter during the passive 55 minutes of every hour, a second "high volume" filter, provided with a filter of the same type, but without a pump, was installed at the same location. The mass collected on this passive filter was subtracted from the mass collected on the other filter, to determine the mass collected during only the active periods. This net mass, along with the volume of air pumped, was used to calculate the weekly-average atmospheric concentration of TSP.

Fine and coarse fractions of the atmospheric aerosol were determined with an Andersen dichotomous sampler with 47 mm filter cartridges. The sampler was controlled by the same controller used for the active high-volume filter. Particles larger than 10 μm were excluded by the virtual impactor of the unit. Coarse particles -- those 2.5 to 10 μm -- were captured on one filter; fine particles -- those 2.5 μm and smaller -- were captured on another. The controller was designed to provide a constant mass rate. The total flow rate through the sampler was adjusted to 16.7 lpm. Both coarse flow and total flow were indicated by rotameters and both were recorded each week, both prior to filter removal, and after the new filters were installed. All filters were changed when the reflectivity measurements were made.

Metecrological data were also obtained. Hourly values for wind speed, wind direction, and rainfall intensity, measured by the National Weather Service at Newark International Airport, were obtained from the National Climate Data Center in North Carolina.

RESULTS

The weekly average ambient concentrations of TSP, fine particles and coarse particles are shown in Figure 1. During the study TSP averaged about 71 $\mu g\ m^{-3}$, the fine fraction about 29 $\mu g\ m^{-3}$, and the coarse fraction about 18 $\mu g\ m^{-3}$. The difference between the TSP and the sum of the two fractional sizes (24 $\mu g\ m^{-3}$) can be attributed to particles larger the 10 μm. TSP was in the range 45-80 $\mu g\ m^{-3}$ over the study period except for week six, when it reached 133 $\mu g\ m^{-3}$.

The particle size distribution was determined by making scanning electron micrographs of each of the painted slides that were exposed for thirteen weeks. Six micrographs were made at each of six magnifications: 100x, 200x, 500x, 1000x, 2000x, and 5000x. The particles on the micrographs were measured and counted, and the number of particles per unit area of receptor surface were calculated. Particle diameters were grouped into size ranges of 1/6 decade diameters from 0.464 micrometers to >68.1 micrometers.

The size of irregular-shaped particles was classified by taking the square root of the product of the width and length. Using this procedure, the maximum error in estimated area coverage by assuming the particles to be round would be an underestimation of the area by 27.3% if all of the particles were rectangular. Since the shape of most irregular particles is closer to round or oval than to rectangular, the actual error is much less.

The results are given in Table 1 and shown in Figures 2 and 3. Because of the large range in the number of particles between the smallest sizes and the largest sizes (more than four orders of magnitude), the particle number data were logarithmically transformed prior to plotting on the figures. Each graph shows a higher concentration of particles on the sheltered panels than on the unsheltered panels, and a particle concentration that falls off rapidly with particle size on all panels. In the fine range, there is little difference between the particle size density on the sheltered and unsheltered panels, but there are slightly more particles on the sheltered panels.

The plots also show a higher density of particles on the horizontal panels than on the vertical ones. This is not unexpected. Turbulent eddies from winds and thermal effects would be expected to bring the particles to the panel surfaces. Upon reaching the boundary layer, the particles can contact it by such mechanisms as diffusion, inertial impaction, interception, electrostatic attraction, and sedimentation.[2,3] Sedimentation, however, does not take place onto vertical surfaces. Impaction and interception would be expected to be significant mechanisms for the deposition onto the vertical panels. The data are consistent with gravitational settling depositing more particles upon the horizontal panels than impaction or interception deposit upon the vertical panels.

Figure 3 shows the area covered by the particles, if they are assumed to be spherical and deposited in a monolayer. These plots show the higher coverage of the panels when they are sheltered. The sheltered, horizontal panel had about 14% of its surface covered by the particles, and particles in the 15 to 30 m size range had the greatest impact. These large particles are present in only small amount on the unsheltered panel -- presumably they were washed off by rain and wind. The small particles, those smaller than about 5 m remain, and have the most impact with this panel. The small particles appear "stickier" than the larger particles. About 3 1/2 % of the surface of the unsheltered panel was covered by particles.

Figure 3 shows a like pattern for the vertical panels. Two differences from the horizontal panels are apparent, however. The area coverage by the particles is less -- about 3% when sheltered and about 2% when not sheltered, and the areal coverage of the sheltered panel is more uniformly the result of all the different sized particles. With the vertical panels, the small particles remain on the unsheltered panel. The vertical panels also have the largest percent coverage of any of the sizes.

The study was conducted during the spring. Rainfalls in excess of one inch per day occurred five times during the study. Figure 4 shows both the weekly rainfall and the maximum 1-hour rainfall during each of the study weeks. During week eight, almost the entire week's rainfall fell in one hour. Weeks 4,8,9 and 11 were rainy. During these weeks the reflectivity of the unsheltered horizontal panel actually increased in three of the readings and fell at an average rate of about 0.6%/week based on three other readings. The reflectivity of the vertical panel fell at an average rate of about 1%/week during these wet weeks. Weeks 2 and 6 were periods of low rainfall. During these weeks the reflectivity of the horizontal panel fell at an average rate of 3.8 %/week, but that of the vertical panel fell at a rate of only 0.7%/week, little different from that during the wet weeks. Intense rains would be expected to wash deposited particles from the exposed panels, and is probably the reason for the lower particle concentrations observed on these exposed panels. The rain seems to diminish the reduction in reflectivity of the horizontal panels but not that of the vertical panels.

The results of the weekly measurements of the reflectivities of the panels are shown on Figures 5 through 8. On these figures, the log of the percent reflectivity measured each week is plotted against the weeks of exposure. The lines are the result of a linear regression of the data. The logarithmic transformation was found to result in a better linear fit.

The data for the unsheltered, horizontal panel (Figure 5) show little difference between the reflectivities of the glossy and the flat paint after about three weeks of exposure. The reflectance of the two paints are essentially the same and constant after 10 weeks of exposure. The unsheltered vertical panel (Figure 6) retained more of its initial refletivity than did the horizontal panel, and on the vertical panel the glossy paint remained more reflective than the flat paint.

The data for the sheltered horizontal panel (Figures 7) show that the glossy paint remains more reflective than the flat paint, and both are less reflective than are the paints on the corresponding unsheltered panel. This is consistent with more deposition remaining on the sheltered panel. The sheltered, vertical panel exhibited essentially no change in reflectivity over the study period. This suggests minimal deposition by interception and impaction since this panel was protected from wash-off by rain.

Both the fine fraction and the coarse fraction of the collected particles, were analyzed for elemental composition from the dichotomous sample filters. Each sample was analyzed for 32 elements, and the results reported in units of ng m^{-3}. For illustration of the typical composition of the ambient air during the study period, one of these analyses is summarized in Figures 9. For simplicity, both of these figures show only the ten most abundant elements in the sample. The major component of the fine particle fraction is sulfur. This would be indicative of a sulfate aerosol, which is a prevalent part of the fine

mass in New Jersey[1]. The major constituent of the coarse particle fraction, on the other hand, is silicon. The abundance of silica and aluminum in the coarse fraction suggests material of either crustal or fly ash origin. Summertime levels of crustal material have been found to be high in Elizabeth [1].

DISCUSSION

The data show that large particles (10 m to >50 m) deposit upon and adhere to both vertically and horizontally oriented sheltered panels and contribute the most to the area of coverage of the panels. This is consistent with earlier work by Haynie[4]. Haynie's earlier work showed a bimodal effect of particle size on soiling. The present work shows a bimodal size distribution on the panels, which is consistent with Haynie[4], and a bimodal area of coverage distribution with a minimum at about 5 m.

The sheltered panels contain more of the large particles (>10 m) than do the unsheltered panels. It appears that the large particles are removed from the unsheltered panels by rain. The amount of fine particles (<2.5 m) are not very different between the two panel orientations.

The higher density of particles on the horizontal panels than on the vertical panels indicates that sedimentation is a significant deposition mechanism with horizontal surfaces.

The reflectivity of the unsheltered, horizontal panel decreased for about the first eight weeks of exposure, and then became nearly constant, with essentially the same value for both the glossy and the flat painted surfaces. When the reflectivity readings were taken staining was seen on the horizontal, unsheltered panel after rains. It appears that an equilibrium is reached between particle deposition and particle wash off and resulting staining. It is not clear if the staining resulted from slurrying of deposited particles and subsequent evaporation of the water, or if it is the result of solubilization of components of the particles, possibly metel salts.

During the study, the reflectivity of the horizontal panel dropped 15% from its initial value when the panel was unsheltered and 21% of its initial value when it was sheltered. The vertical panel dropped 7% in reflectivity when unsheltered and only 1.5% when it was sheltered.

ACKNOWLEDGMENT

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Publishers, Inc., 1987.

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3. William C. Hinds, Aerosol Technology, John Wiley and Sons, 1982.

4. Fred H. Haynie, "Size Distribution of Particles That May Contribute to Soiling of Material Surfaces", Journal of the Air Pollution Control Association, 35:552 (1985).

TABLE 1
PARTICLE SIZE STATISTICS

DIAMETER RANGE m	MIDPOINT OF RANGE	HORIZONTAL PANELS UNSHELTERED NUMBER OF PARTICLES PER SQ MM	HORIZONTAL PANELS UNSHELTERED PERCENT OF PANEL COVERED BY PARTICLES	HORIZONTAL PANELS SHELTERED NUMBER OF PARTICLES PER SQ MM	HORIZONTAL PANELS SHELTERED PERCENT OF PANEL COVERED BY PARTICLES
>68.1	82.54	-	-	0.75	0.401
46.4 - 68.1	56.20	0.39	0.097	1.75	0.435
31.6 - 46.4	38.30	0.39	0.045	10.40	1.199
21.5 - 31.6	26.10	2.15	0.115	42.00	2.247
14.7 - 21.5	17.70	5.61	0.139	90.30	2.242
10.0 - 14.7	12.20	12.56	0.147	162.80	1.903
6.81 - 10.0	8.20	44.50	0.238	245.00	1.310
4.64 - 6.81	5.60	129.40	0.321	402.00	0.997
3.16 - 4.64	3.80	449.00	0.517	555.00	0.639
2.15 - 3.16	2.60	865.00	0.463	1282.00	0.686
1.47 - 2.15	1.70	1227.00	0.305	2594.00	0.646
1.00 - 1.47	1.20	3847.00	0.442	3677.00	0.423
.681 - 1.00	0.80	7634.00	0.413	6548.00	0.354
0.464 - 0.681	0.50	9469.00	0.233	15000.00	0.369
		23686.00	3.475	30611.00	13.851

DIAMETER RANGE m	MIDPOINT OF RANGE	VERTICAL PANELS UNSHELTERED NUMBER OF PARTICLES PER SQ MM	VERTICAL PANELS UNSHELTERED PERCENT OF PANEL COVERED BY PARTICLES	VERTICAL PANELS SHELTERED NUMBER OF PARTICLES PER SQ MM	VERTICAL PANELS SHELTERED PERCENT OF PANEL COVERED BY PARTICLES
>68.1	82.54	-	-	-	-
46.4 - 68.1	56.23	0.19	0.047	0.47	0.117
31.6 - 46.4	38.31	0.19	0.022	1.87	0.216
21.5 - 31.6	26.10	1.71	0.091	3.53	0.189
14.7 - 21.5	17.78	4.63	0.115	8.83	0.219
10.0 - 14.7	12.20	10.98	0.128	20.40	0.238
6.81 - 10.0	8.25	24.70	0.132	38.20	0.204
4.64 - 6.81	5.62	58.00	0.144	62.90	0.156
3.16 - 4.64	3.83	174.60	0.201	237.80	0.274
2.15 - 3.16	2.61	375.00	0.201	447.00	0.239
1.47 - 2.15	1.78	1070.00	0.266	1050.00	0.261
1.00 - 1.47	1.21	2000.00	0.230	2086.00	0.240
0.681 - 1.00	0.83	4200.00	0.227	5087.00	0.275
0.464 - 0.681	0.56	5500.00	0.135	7543.00	0.186
		13420.00	1.941	16587.00	2.814

FIGURE 1

AMBIENT AEROSOL CONCENTRATIONS

TSP, FINE PARTICLES AND COARSE PARTICLES

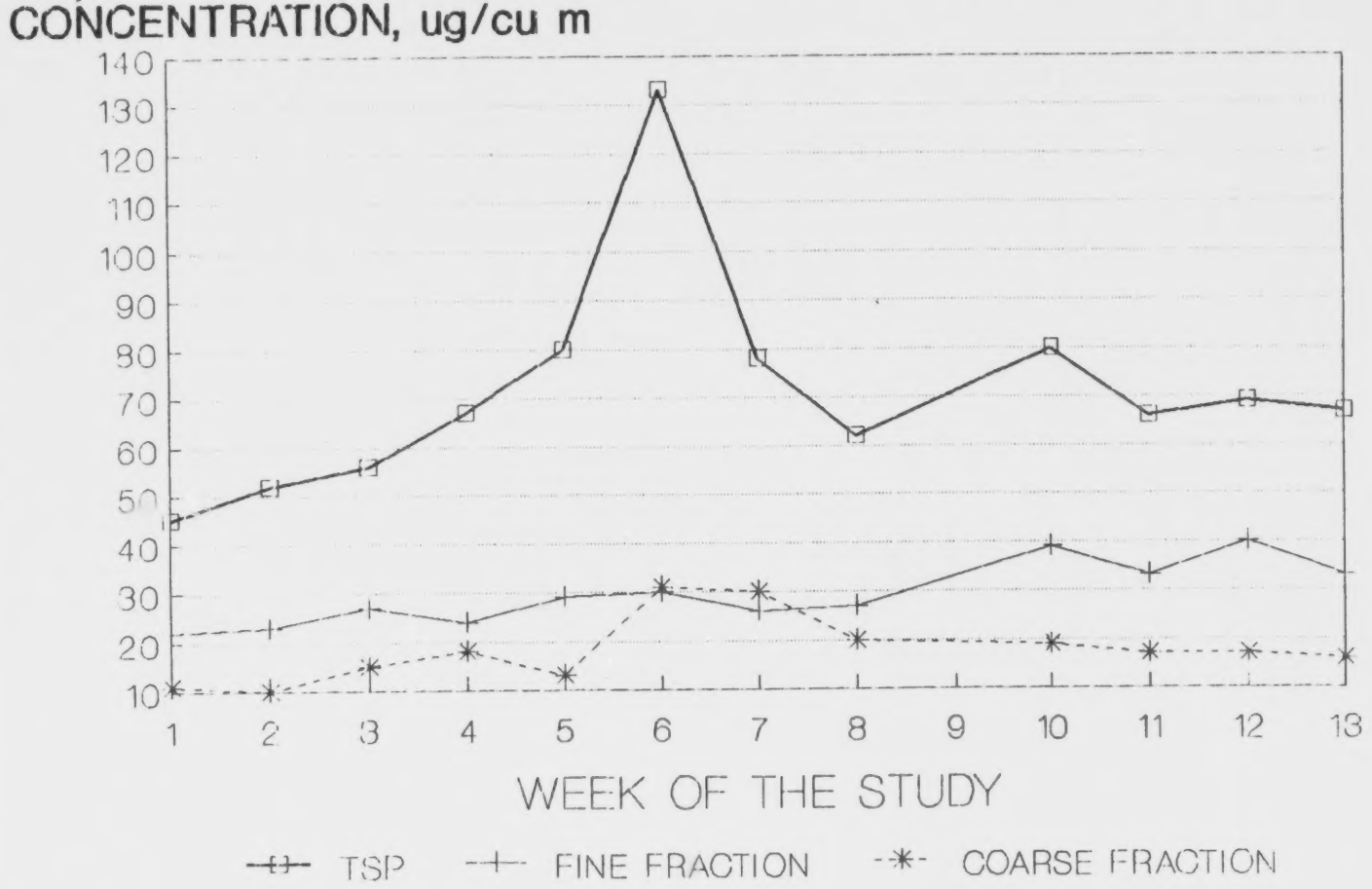
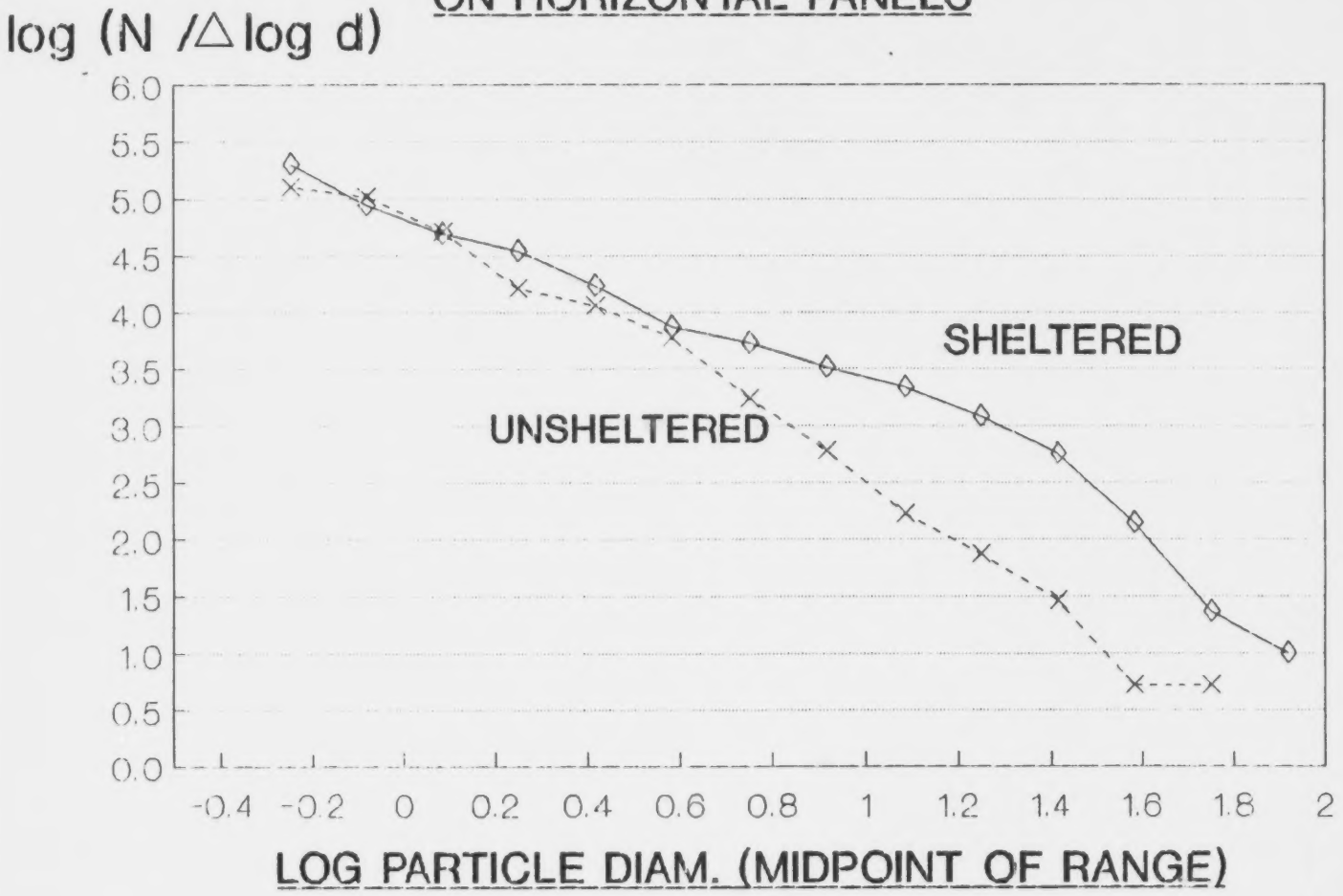
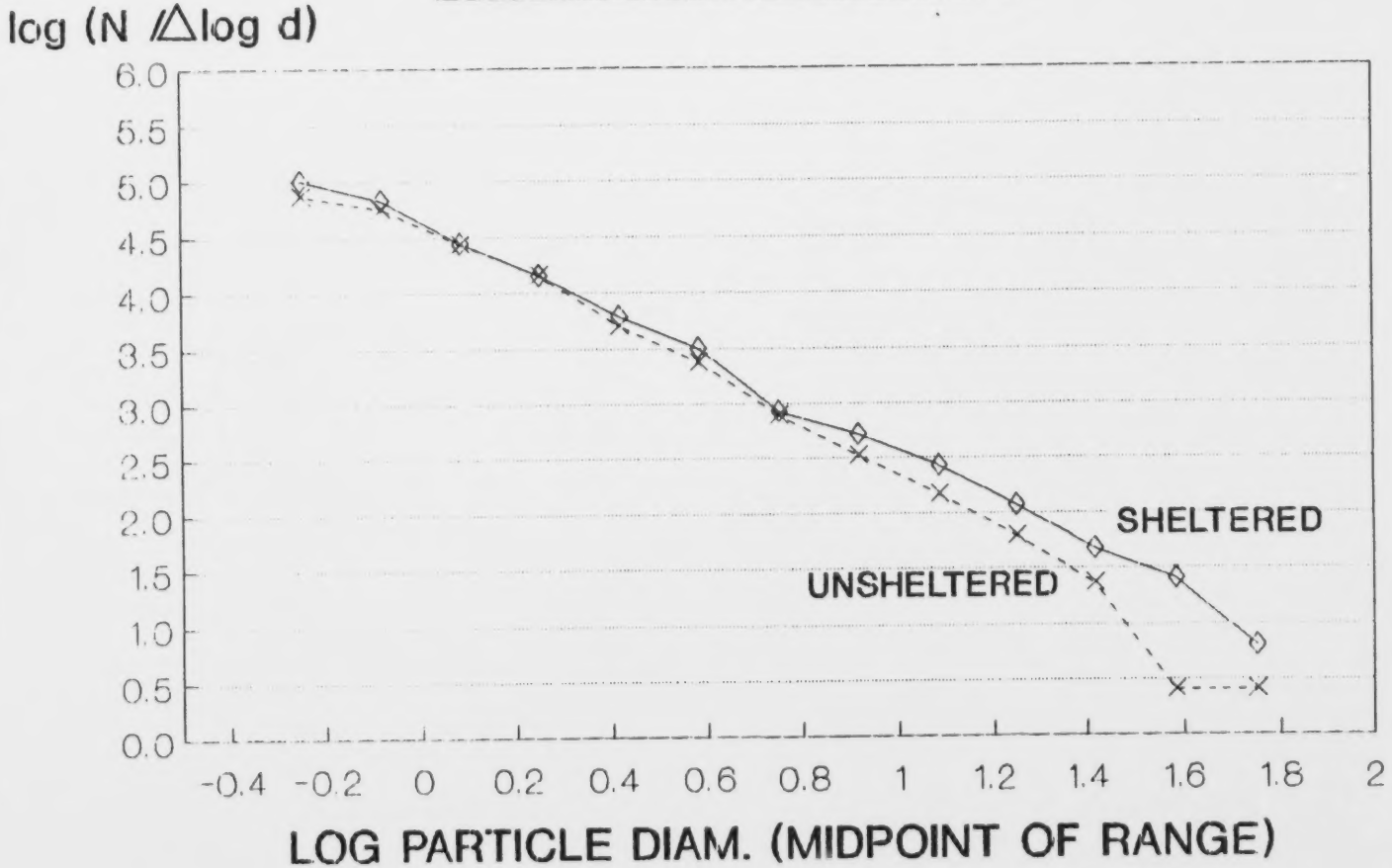


FIGURE 2. PARTICLE SIZE DISTRIBUTIONS ON HORIZONTAL PANELS



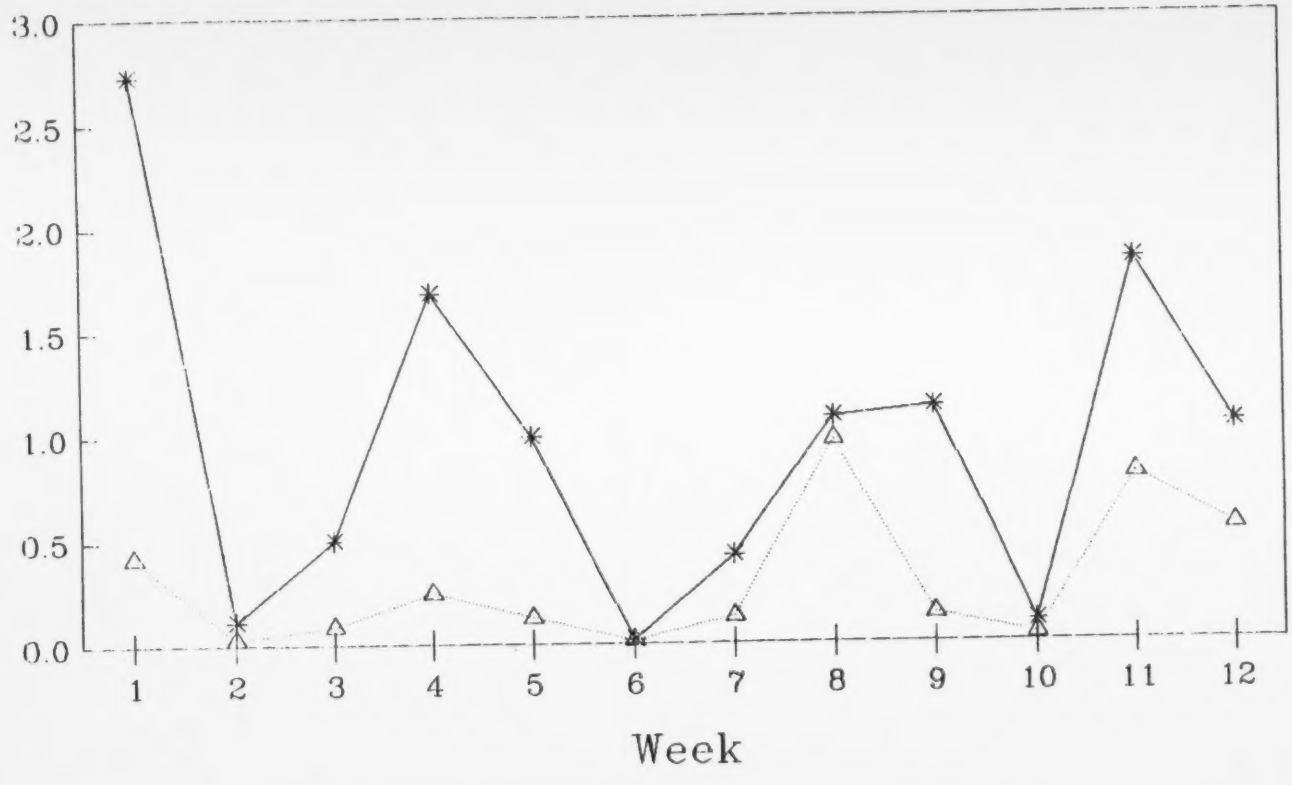
Particle Size in Micrometers
Number in Counts per Sq. mm

FIGURE 3. PARTICLE SIZE DISTRIBUTIONS ON VERTICAL PANELS



Particle Size in Micrometers
Number in Counts per Sq. mm

FIGURE 4 – METEOROLOGICAL DATA
1987 ELIZABETH SOILING STUDY



DATA FOR NEWARK AIRPORT

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FIGURE 5 AREA COVERED BY PARTICLES HORIZONTAL PANELS

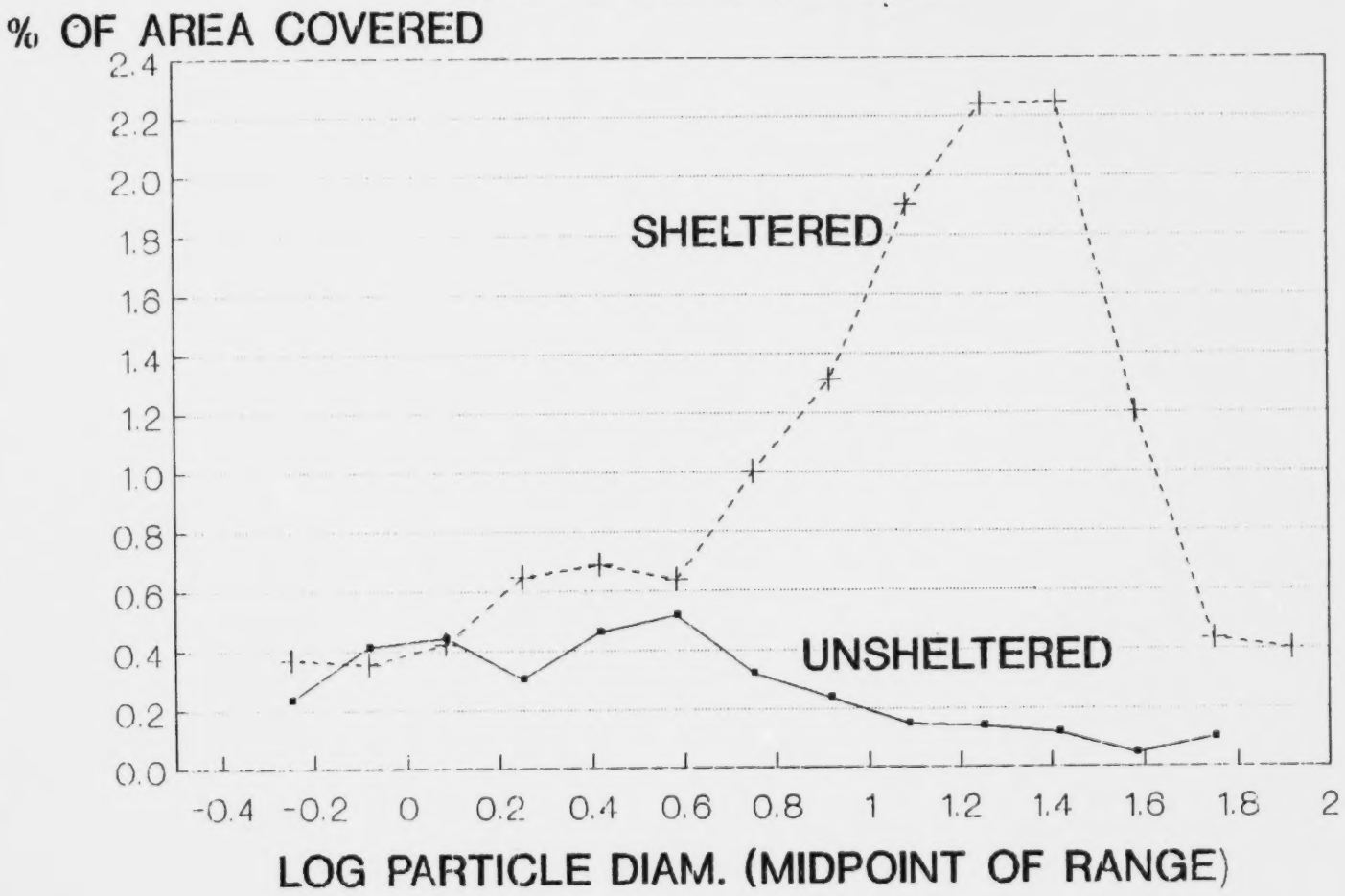

FIGURE 6 - AREA COVERED BY PARTICLES VERTICAL PANELS

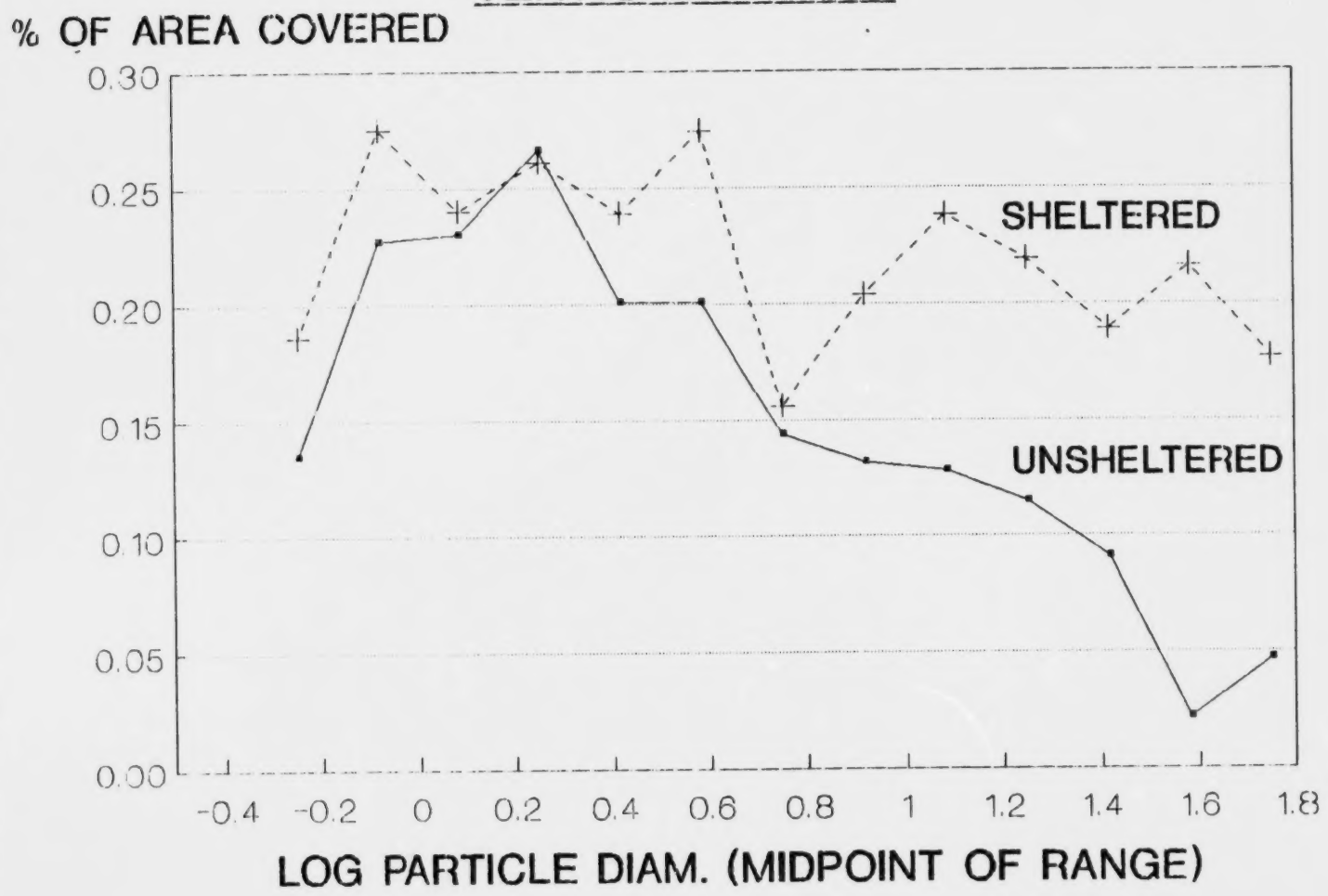

FIGURE 7– LOG OF REFLECTIVITY VS. WEEKS
UNSHELTERED HORIZONTAL PANELS

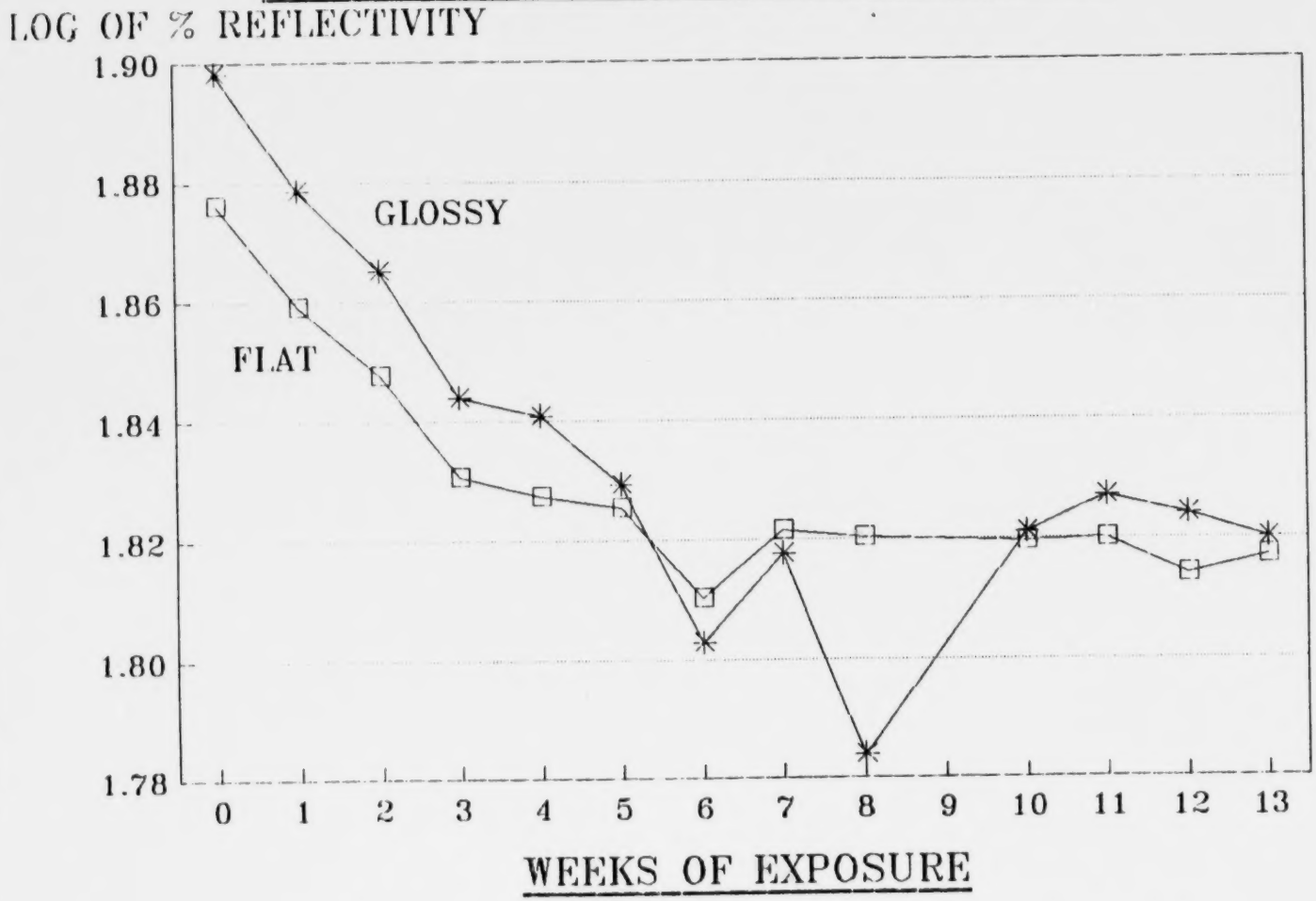

FIGURE 8 -- LOG REFLECTIVITY VS. WEEKS
UNSHELTERED VERTICAL PANELS

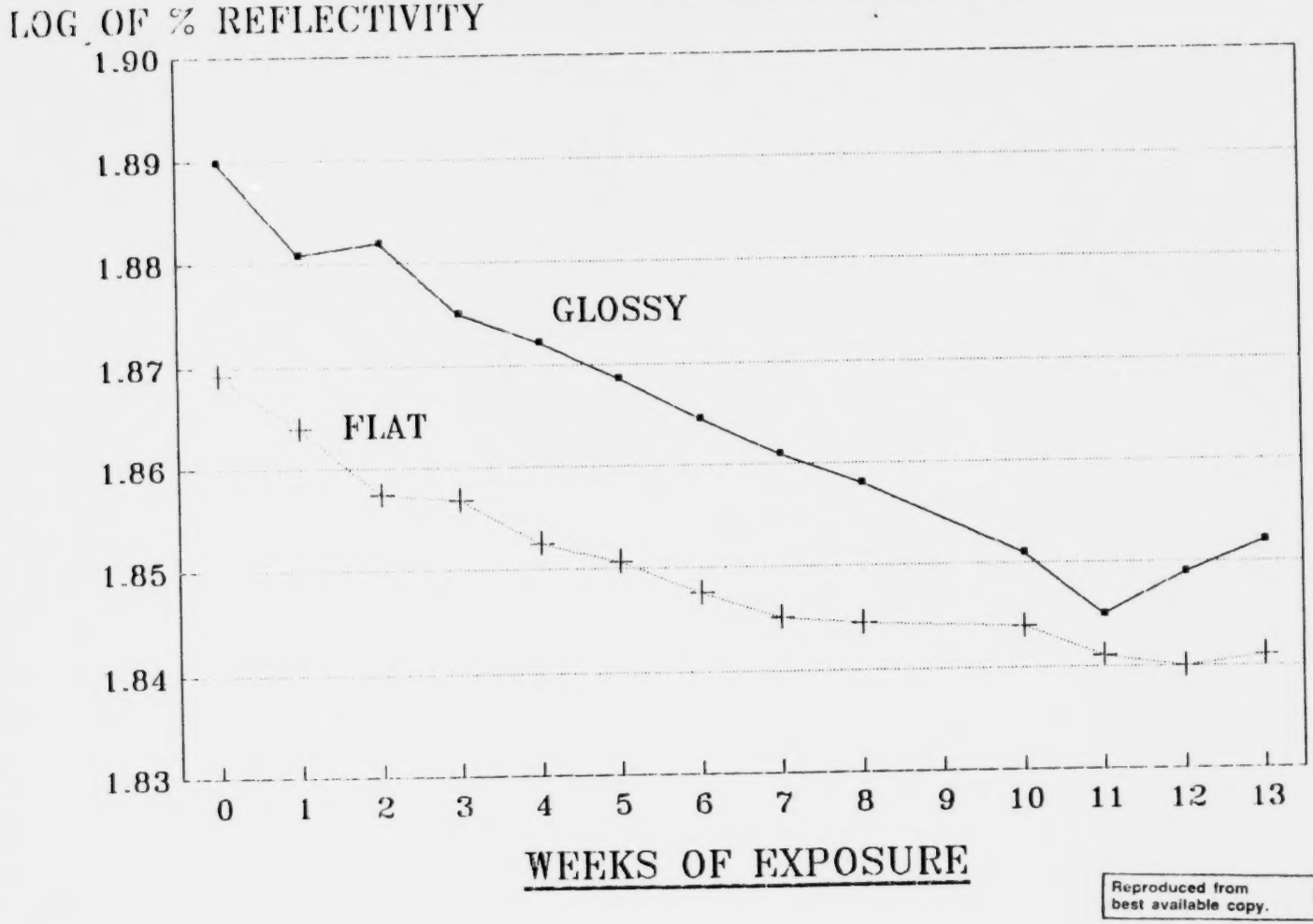

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FIGURE 9– LOG OF REFLECTIVITY VS. WEEKS
SHELTERED HORIZONTAL PANELS

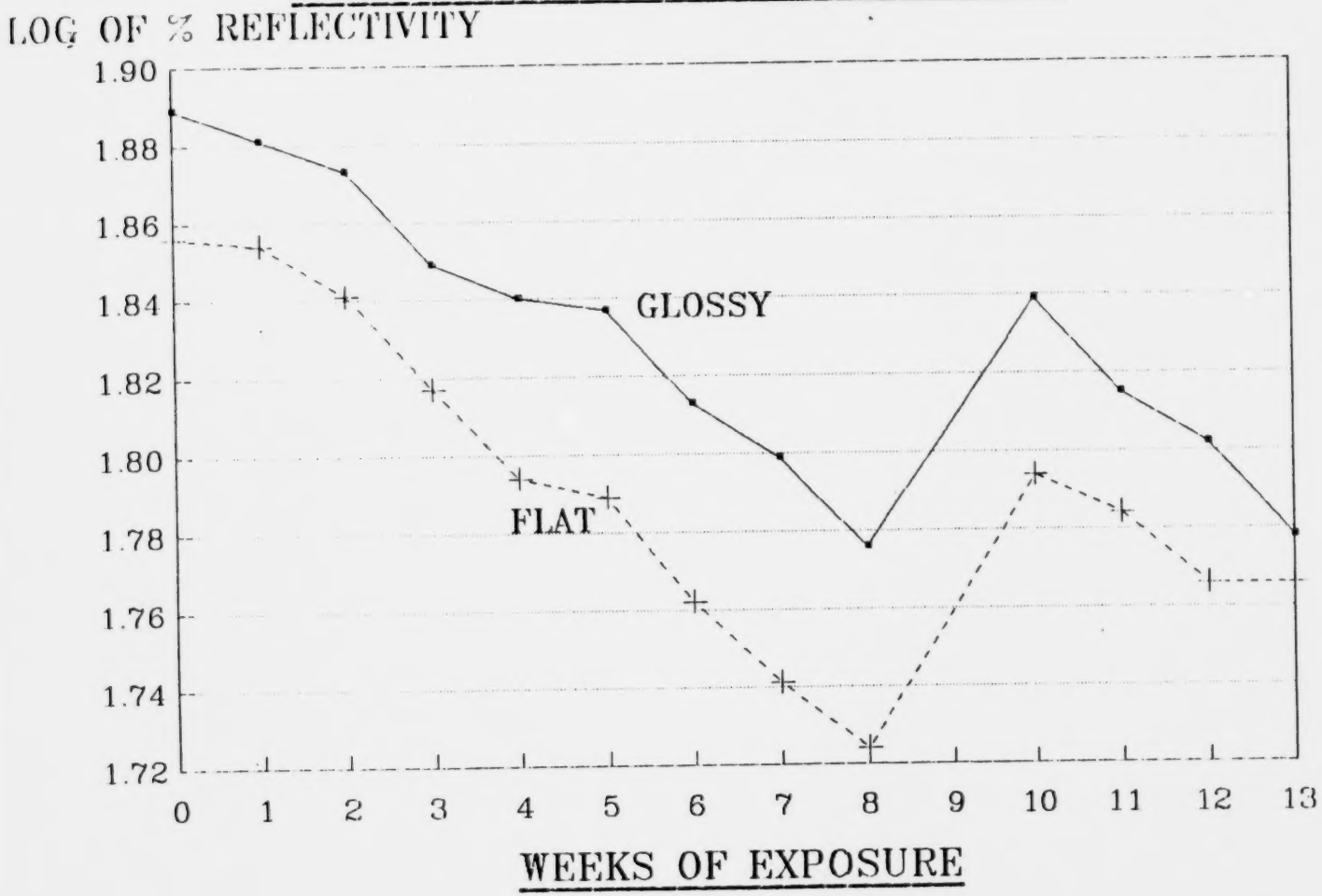

FIGURE 10 – LOG REFLECTIVITY VS. WEEKS
SHELTERED VERTICAL PANELS

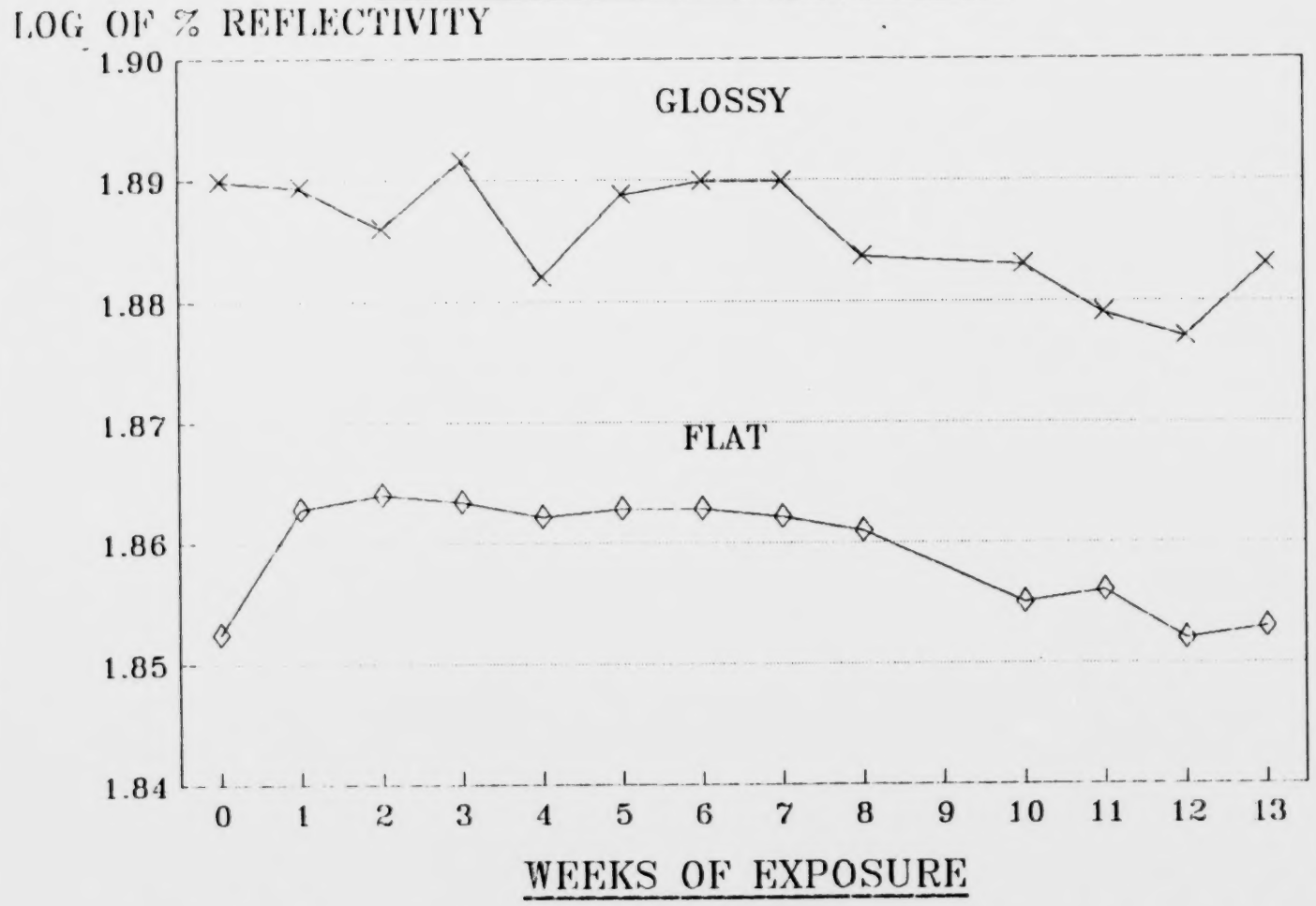

FIGURE 11 — ELEMENTAL COMPOSITION
FINE PARTICLE FRACTION, NG/CU. M

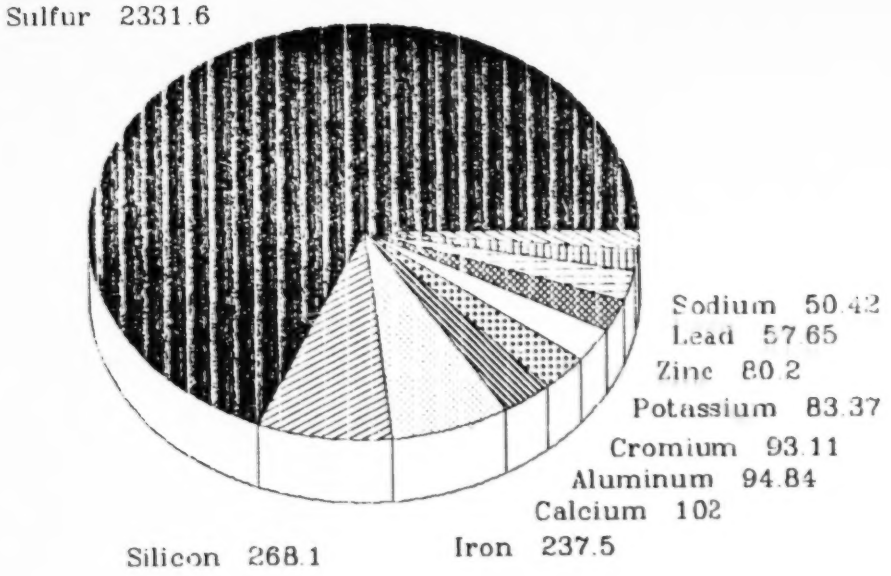

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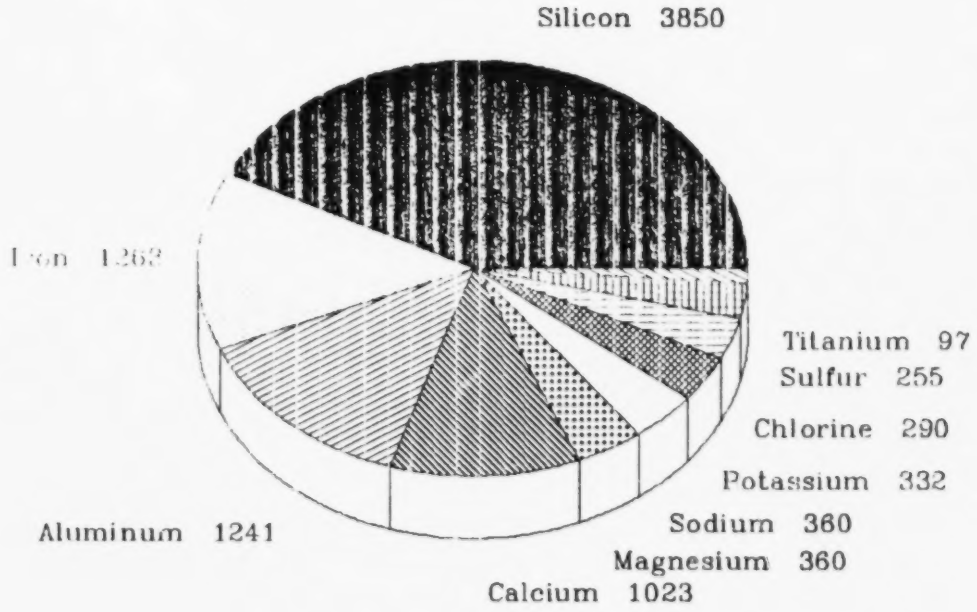
FIGURE 12 – ELEMENTAL COMPOSITION
COARSE PARTICAL FRACTION, NG/CU. M



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